APPENDIX - F

SPECIFICATIONS FOR GPS SURVEYS

BUREAU OF DESIGN AND ENVIRONMENT

SURVEY MANUAL

May 2001

SPECIFICATIONS FOR GPS SURVEYS

ILLINOIS

DEPARTMENT OF TRANSPORTATION

DIVISION OF HIGHWAYS

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SPECIFICATIONS FOR GPS SURVEYS

I. GENERAL

A. INTRODUCTION

The following specifications set forth the minimum requirements that must be met by the CONSULTANT when providing GPS (Global Positioning System) data to the Illinois Department of Transportation (IDOT).

B. NETWORK DESIGN AND CONNECTIONS

The location of the new control points shall depend on the optimum layout to carry out the required needs of the survey.

Checks shall be made to ensure that no existing or known network control points have been moved or disturbed. If any are doubtful, additional existing points shall be tied into the network.

Horizontal networks shall be connected to a minimum of three National Geodetic Survey (NGS) first-order or higher stations or four stations if any NGS second-order stations are used. If only a horizontal survey is being done, at least one bench mark shall be used and held fixed in the adjustment. The use of eccentric horizontal stations is not permitted.

Vertical networks shall be connected to three or more NGS elevation marks of first or second-order accuracy. At least three of the known bench marks shall be near the boundary of the project or outside of the project area to best define the geoid separation for the project. In areas of sparse NGS vertical control, contact IDOT for alternative bench marks. The use of eccentric vertical stations is permitted provided they are located within 100 meters of the original mark and three (3) wire leveling, done to Second-Order Class II accuracy, is used to determine the elevation of the eccentric point.

The existing control, both horizontal and vertical, used to control a network shall lie in a minimum of three quadrants using the geographic center of the project as the reference point.

Direct connections should be performed if practical, between adjacent stations designated by IDOT and located within ten kilometers of the project area.

Azimuth marks can be established by GPS procedures. Station pairs, to provide azimuths, are to be established at intervals no greater than 10 kilometers along the project length. Station pairs (station and azimuth) are to be intervisible at normal tripod heights and spaced not less than 500 meters apart.

All network designs shall be submitted to the appropriate IDOT office for approval prior to making observations unless stated otherwise in the Scope of Services meeting.

C. INSTRUMENTATION

The receivers used shall be dual frequency and shall have the capability of tracking a minimum of five GPS satellites simultaneously.

The receivers shall have the capability to receive and decode the C/A (Coarse Acquisition) code and the P(Precise) code data on the L1 frequency and the P code on the L2 frequency. The instruments shall be able to handle the encrypted P code.

The manufacturers predetermined phase center height for the antenna used shall be noted on each data sheet.

II. FIELD PROCEDURES

A. GENERAL

The precision of the GPS vector base line results depends on the number of satellites visible simultaneously from each station during an observing session, their geometric relationships, duration of the period when the desired number of satellites can be observed simultaneously, the uncorrected effects of ionospheric and tropospheric refraction, and the length of line. The number of possible observing sessions per observing day is a function of the required survey accuracy, satellite availability, and project logistical considerations such as travel and set up time required between observing sessions.

The specifications for the field procedures for all surveys within the scope of the agreement will be as outlined in Section B. Section B describes the various modes of data collection approved by the IDOT. The GPS surveys shall be accomplished to meet a minimum accuracy of 1:50,000. A higher accuracy may be required on selected projects and will be outlined in the Scope of Services for the project.

B. FIELD PROCEDURES FOR DUAL FREQUENCY RECEIVERS

B.1 Static Observations

B.1.1 Static observations are required for all base lines over 25 kilometers in length. Static observations may be required for some lines less than 25 kilometers. Requirements for these measurements will be made on a project by project basis by IDOT personnel.

B.1.2 A minimum of three receivers shall be used simultaneously during all static GPS sessions.

B.1.3 A minimum of five satellites shall be observed simultaneously for a minimum of 30 minutes plus one minute per kilometer of base line length per session. At no time during the observing session shall the Geometric Dilution of Precision (GDOP) be greater than 8. The Position Dilution of Precision (PDOP) shall not be greater than 5.

B.1.4 Data sampling shall have an epoch time interval of 15 seconds or less.

B.1.5 Satellite signals shall be observed from a minimum of two quadrants that are diagonally opposite of each other.

B.1.6 Obstructions that are twenty degrees (20°) or more above the horizon shall be noted on an obstruction diagram. The effect of obstructions shall be minimized by proper mission planning.

B.1.7 Satellite data below an elevation mask of fifteen degrees (15°) shall not be used in base line measurements.

B.2 Rapid (Fast) Static Observations

B.2.1 A minimum of three receivers shall be used simultaneously during all rapid static GPS sessions. Rapid static procedures may be used on base lines up to 25 kilometers in length.

B.2.2 For each session a minimum of five satellites shall be observed simultaneously for a minimum of 5 minutes plus one minute per kilometer of base line length per session for base lines up to 10 kilometers. For base lines ranging from 10 kilometers to 25 kilometers a minimum observation of 10 minutes plus one minute per kilometer shall be observed. At any point in time during the session the GDOP shall not be greater than 6. The PDOP shall not be greater than 5.

B.2.3 Data sampling shall have an epoch time interval of 5 seconds or less.

B.2.4 Satellite signals shall be observed from a minimum of two quadrants that are diagonally opposite of each other.

B.2.5 Obstructions that are twenty degrees (20°) or more above the horizon shall be noted on an obstruction diagram. The effect of obstructions shall be minimized by proper mission planning.

B.2.6 Satellite data below an elevation mask of fifteen degrees (15°) shall not be used in base line measurements.

B.3 Stop and Go Observations (For base lines < 5 km)

B.3.1 A minimum of three receivers shall be used simultaneously during all Stop and Go GPS sessions. Two receivers shall occupy reference stations and one receiver will be the rover. This procedure shall be limited to base lines of 5 kilometers or less.

B.3.2 A minimum of five satellites shall be observed simultaneously for a minimum of 5 epochs. At any point in time during the session the GDOP shall not be greater than 6. The PDOP shall not be greater than 5.

B.3.3 Initialization of the roving receiver can be accomplished by occupying a known point for a minimum of 5 epochs or making a rapid static observation on the first new point for 5 minutes plus one minute per kilometer, using the distance to the furthermost reference receiver, and then moving to other points to be surveyed.

B.3.4 Data sampling shall have an epoch time interval of 3 seconds or less. A minimum of 3 epochs must be recorded for each point located.

B.3.5 Satellite signals shall be observed from a minimum of two quadrants that are diagonally opposite of each other.

B.3.6 Obstructions that are twenty degrees (20°) or more above the horizon shall be noted on an obstruction diagram. The effect of obstructions shall be minimized by proper mission planning.

B.3.7 Satellite data below an elevation mask of fifteen degrees (15°) shall not be used in base line measurements.

B.4 Reoccupation Observations

B.4.1 A minimum of three receivers shall be used simultaneously during all Reoccupation GPS sessions.

B.4.2 A minimum of five satellites shall be observed simultaneously for a minimum of 5 minutes plus one minute per kilometer of base line length per session for base lines up to 10 kilometers. For base lines ranging from 10 kilometers to 25 kilometers a minimum observation of 10 minutes plus one minute per kilometer shall be observed. At any point in time during the session the GDOP shall not be greater than 6. The PDOP shall not be greater than 5. All points surveyed must be re-occupied after at least one hour has elapsed to allow for a different alignment of the satellites. This method is not recommended unless the satellite configuration or site conditions do not permit rapid static procedures.

B.4.3 Data sampling shall have an epoch time interval of 5 seconds or less.

B.4.4 Satellite signals shall be observed from a minimum of two quadrants that are diagonally opposite of each other.

B.4.5 Obstructions that are twenty degrees (20°) or more above the horizon shall be noted on an obstruction diagram. The effect of obstructions shall be minimized by proper mission planning.

B.4.6 Satellite data below an elevation mask of fifteen degrees (15°) shall not be used in base line measurements.

B.5 Kinematic Observations

B.5.1 A minimum of three receivers shall be used simultaneously during all kinematic GPS sessions. Two receivers shall occupy reference stations and one receiver shall be the rover.

B.5.2 A minimum of five satellites shall be observed simultaneously. At any point in time during the session the GDOP shall not be greater than 6. The PDOP shall not be greater than 5.

B.5.3 Initialization of the roving receiver can be accomplished by occupying a known point for a minimum of 5 epochs or making a rapid static observation on the first new point for 5 minutes plus one minute per kilometer, using the distance to the furthermost reference receiver and then moving to other points to be surveyed.

B.5.4 Data sampling shall have an epoch time interval of 2 seconds or less.

B.5.5 Satellite signals shall be observed from a minimum of two quadrants that are diagonally opposite of each other.

B.5.6 Obstructions that are twenty degrees (20°) or more above the horizon shall be noted on an obstruction diagram. The effect of obstructions shall be minimized by proper mission planning.

B.5.7 Satellite data below an elevation mask of fifteen degrees (15°) shall not be used in base line measurements.

B.6 Real-Time Kinematic Observations (Base lines < 3 km)

B.6.1 A minimum of two receivers must be used simultaneously during all real-time kinematic GPS sessions. One receiver (master) shall occupy a reference point and one or more receivers shall be used as rovers.

B.6.2 A minimum of five satellites shall be observed simultaneously. At any point in time during the session the GDOP shall not be greater than 6. The PDOP shall not be greater than 5.

B.6.3 Initialization of the roving receiver can be accomplished by occupying a known point for a minimum of 5 epochs or making a rapid static observation on the first new point for 5 minutes plus one minute per kilometer, using the distance to the reference receiver and then moving to other unknown points.

B.6.4 Data sampling shall have an epoch time interval of 2 seconds or less. Real-Time coordinates must be recorded. The raw data shall be recorded for post processing.

B.6.5 Satellite signals shall be observed from a minimum of two quadrants that are diagonally opposite of each other.

B.6.6 Obstructions that are twenty degrees (20°) or more above the horizon shall be noted on an obstruction diagram. The effect of obstructions shall be minimized by proper mission planning.

B.6.7 Satellite data below an elevation mask of fifteen degrees (15°) shall not be used in base line measurements.

C. INDEPENDENT OCCUPATIONS PER STATION

The following criteria in this section pertains to static, rapid static and reoccupation procedures for network adjustments. Occupied means one observing session.

C.1 Ten percent of all stations shall be occupied three times or more.

C.2 Thirty percent of new stations shall be occupied two or more times.

C.3 One hundred percent of vertical control stations shall be occupied two or more times.

C.4 Twenty-five percent of horizontal control stations shall be occupied two or more times.

C.5 One hundred percent of "station pairs" for azimuth control shall be occupied simultaneously two or more times.

C.6 One hundred percent of new vertical stations shall be occupied two or more times.

C.7 When a station is occupied during back to back sessions, the antenna/tripod must be reset between the sessions to be classified as an independent occupation.

D. ANTENNA SET UP

D.1 The number of antenna height measurements per session shall not be less than two.

D.2 Antenna height measurements shall be in feet or meters.

D.3 It is highly recommended that a fixed height pole be used to hold the antenna. This eliminates any possible errors in determining the antenna height.

E. MONUMENTATION

E.1 Permanent type monuments shall be placed at all "station pairs". Monuments shall meet IDOT specifications as per the Highway Standards Manual, Standard #2135. All permanently monumented stations shall be fully described with "To Reach" descriptions and local ties.

E.2 Iron pins with a minimum size of 5/8" diameter by 30" in length shall be used for control stations, unless specified differently in the Scope of Services for a specific project. IDOT will furnish plastic caps to fit the 5/8" diameter re-bar.

F.3 All new stations shall be described using sketches and local ties.

III. OFFICE PROCEDURES

A. GENERAL

Software used for processing the raw data must be capable of producing results that meet the accuracy standards specified for the survey.

The software must be able to produce from the raw data relative position coordinates and corresponding variance -covariance statistics which in turn can be used as input to three dimensional network adjustment programs.

The 1999 or later version of the Geoid Model shall be used for elevation determinations.

A three dimensional least squares adjustment shall be made to provide final adjusted coordinates of the GPS network control stations. All NGS control stations (1997 adjustment) are to be held in the adjustment, unless proven that the station does not meet the required accuracy.

B. LOOP CLOSURE ANALYSIS

The following list of occupation rates shall be used for static and rapid static procedures for network adjusting.

B.1 Base lines in the loop shall be from a minimum of two independent observation sessions.

B.2 Base lines in the loop shall not total more than ten.

B.3 Loop length shall not exceed 100 kilometers.

B.4 Percentage of base lines not meeting criteria for inclusion in any loop shall be less than 30% of all independent base lines.

B.5 In any component (XYZ) maximum misclosure shall not exceed 25 cm.

B.6 In any component (XYZ) maximum misclosure in terms of loop length shall not exceed 12.5 ppm.

B.7 In any component (XYZ) the average misclosure in terms of loop length shall not exceed 8 ppm.

C. REPEAT BASE LINE DIFFERENCE

C.1. Base line length not to exceed 50 kilometers.

C.2. In any component (XYZ) maximum difference shall not exceed 10 ppm.

D. MATERIAL TO BE DELIVERED

The following data shall be submitted to _____ upon completion of the horizontal and vertical control work.

D.1 Original GPS raw data on 3½ inch HD diskettes or on CD's in either LEICA or RINEX format.

D.2 Listings of loop closure analysis.

D.3 Listing of Geographic Coordinates, ellipsoidal heights, and geoid separations for all stations.

D.4 Listings of final State Plane Coordinates shall be in U.S. Survey Feet or Meters depending on project requirements and shall be referenced to the North American Datum of 1983 (NAD83) (1997*)* East or West Zone and the elevations of all stations shall be referenced to the North American Vertical Datum of 1988 (NAVD88).

D.5 Map showing all measured base lines.

D.6 A report of the minimally constrained three dimensional (3D) adjustment holding the latitude and longitude of one National Geodetic Reference System 1980 (NGRS) station and the ellipsoidal height of an existing bench mark. This will be used to analyze the contractor's field work.

D.7 A report of the constrained 3D adjustment holding the latitude and longitude of all NGRS horizontal stations and all bench marks. This will be used to analyze how well this project fits within the NGRS from a three dimensional mapping standpoint.

D.8 A written report including obstruction charts and events logs.

IV. GPS SPECIFICATIONS FOR PHOTOGRAMMETRIC CONTROL

A. INTRODUCTION

These specifications set forth the minimum requirements for utilizing GPS techniques to establish horizontal and vertical control used in photogrammetric mapping projects.

B. LOCATION MAPPING (1:2500)

Only static and rapid static procedures as outlined in Section II of these specifications shall be used to obtain the horizontal and vertical positions of aerial survey control points. All coordinates shall be established using the North American Datum of 1983 (1997 adjustment) for the horizontal datum and the North American Vertical Datum of 1988 for the vertical reference datum. The latest version available for the geoid model shall be used in determining the orthometric heights for the control points established for a photogrammetric project.

C. DESIGN MAPPING (1:500)

Static and rapid static procedures shall be used as outlined in Section II of these specifications to establish the horizontal control positions for the aerial points. Vertical control can be established by GPS procedures provided 95% of all tested points meet or exceed an accuracy of 30 mm. Elevations of a minimum of 10% of the vertical control points shall be determined by conventional means to use as a quality control measure.

D. NETWORK DESIGN

All points must be surveyed to allow loop closures to be calculated using data from a minimum of two sessions to form a loop. If control is required to be brought to the project, a static or rapid static survey should be done to establish project base control. These base stations then are to be used to establish the project control points. A least squares adjustment is required to be completed for all control points established for a photogrammetric project.

E. CRITERIA FOR ESTABLISHING PROJECT CONTROL POINTS

E.1 Procedure 1: Project Framework and Photo Control Points

E.1.1. Project Framework

E.1.1.1 Control points should be established to create a framework around the project. This framework is used to control the project targets.

E.1.1.2 A framework point can be a NGS horizontal station, a NGS vertical station, a USGS monument, or an arbitrary point.

E.1.1.3 If framework points do not already exist, then a second-order or higher network must be established to bring control into the project area to establish the required points.

E.1.1.4 Framework points can be located up to 5 km (3 miles) from the main line of the project. Spacing along the project can be up to 8 km (5 miles) apart.

E.1.1.5 Framework points shall have x, y and z values. If the x, y, and z do not already exist, they should be established using a GPS network. See Sections I, II and III of these specifications.

E.1.2 Photo Control Points

Nearly all photo projects are now pre-targeted. Targets are placed along the centerline of the project as well as along both the outer edges of the photography. These outer edge points are referred to as wing points.

E.1.2.1 Every fifth wing point target must be tied to a framework point or a centerline point to strengthen the control.

E.1.2.2 Two measurements must be made between consecutive targets along the centerline or the wing line of targets.

E.1.2.3 If vertical control is going to be established for the targets using GPS, then all targets must be occupied a minimum of two times.

E.1.2.4 There should be enough redundancy in the line measurements to be able to eliminate a few lines (up to 10%) and still compute the job without returning to the field.

E.1.2.5 At approximately 5 miles or 8 km spacing along the alignment a tie should be made to a framework point.

E.1.2.6 All office procedures in Section III, Item B "Loop Closure Analysis" must be met when using this procedure for photo control.

E.2 Procedure 2: Horizontal Targets Along Center of Corridor (No wing targets).

E.2.1 All horizontal targets are spaced along the centerline of a given corridor or centerline as recommended by the Aerial Surveys Section.

E.2.2 If first-order or higher NGS control lies within 25 km of the ends of the project, a GPS traverse can be run between two first-order or higher NGS stations. If the monumentation does not meet the 25 km restrictions, a network must be established to bring control to the project site. Follow the procedures as outlined in Section I, II and III of theses specifications to do a network.

E.2.3 All distances between traverse stations must be measured twice.

E.2.4 Two known bench marks (preferably NGS) with NAVD88 elevations must be occupied near the ends of the project.

E 2.5 It is recommended that wing points be set away from the main traverse line at 8 km (5 miles) spacing along the project corridor to help strengthen the horizontal coordinates.

E 2.6 If a measurement between two traverse stations proves to be in error during final analysis, it must be re-measured and incorporated in the final adjustment before submitting to Aerial Surveys.

E 2.7 All office procedures in Section III, Item B "Loop Closure Analysis" must be met when using this procedure for photo control.

F. MATERIAL TO BE DELIVERED

See Section III, Item D, page F-7 of these specifications for materials to be delivered for GPS surveys.

V. GPS SPECIFICATIONS FOR TOPOGRAPHIC SURVEYS

A. INTRODUCTION

These specifications set forth the minimum requirements for utilizing GPS techniques to establish horizontal and vertical control and the topographic data points for an IDOT planning or design survey.

B. NETWORK DESIGN

If known control does not already exist within 25 km of the ends of a project, it is required that a static or a rapid static survey be done to establish second order control at the project site to be used for the topographic survey. All points must be surveyed to

allow loop closures to be calculated using data from a minimum of two sessions to form a loop. These base stations then are to be used to establish the project data points. A least squares adjustment is required to be completed for all control points established when performing a static or rapid static survey.

C. CRITERIA FOR ESTABLISHING PROJECT CONTROL POINTS

1. If first-order or higher NGS control lies within 25 km of the ends of the project, a GPS traverse can be run between two first-order or higher NGS stations. If the monumentation does not meet the 25 km restrictions, a network must be established to bring control to the project site. Follow the procedures as outlined in Section I, II and III of theses specifications to do a network.

2. All distances between traverse stations must be measured twice.

3. Two known bench marks (preferably NGS) with NAVD88 elevations must be occupied near the ends of the project. If the horizontal stations do not have vertical information, then bench marks must be occupied.

4. It is recommended that wing points be set away from the main traverse line at 5 miles (8 km) spacing along the project corridor to help strengthen the horizontal coordinates.

5. All office procedures in Section III, Item B “Loop Closure Analysis” must be met when using this procedure for base control.

D. TOPOGRAPHIC DESIGN AND MAPPING DATA COLLECTION

The GPS method of Stop and Go is the most efficient one to use in collecting topographic data for mapping and design purposes. Stop and Go procedures shall be used as outlined in Section II of these specifications to establish the horizontal and vertical positions for the topo points. When collecting topo data the roving receiver shall return to a known point after every 50 data points to perform a check on the system.

E. MATERIAL TO BE DELIVERED

See Section III, Item D, page F-7 of these specifications for the materials to be delivered for GPS surveys.